National Institute of Information and Communications Technology

Working Group Meeting on Space-based Lidar Winds

(*March. 22, 2017, Newport news VA*)

Recent research and development for 2-micron coherent Doppler Wind Lidar

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Outline

- Background and Objective
- Concept of future space-based Doppler Wind Lidar
- Development of high pulse-energy 2-μm laser
- Signal flow considerations
- High-speed 2-μm detector
- Data rate considerations
- Summary

Background and Objective

◆ Background

- Global wind profile observation is important for global numerical weather prediction.
- WMO technical report 2012-1
  - Development of satellite-based wind profiling systems remains a priority for the future global observing system.
- ESA is planning to launch the first space-borne Doppler Wind Lidar (DWL) ADM-Aeolus for obtaining LOS wind profiles.
- In Japan, science working group studied feasibility of the ISS-borne coherent Doppler wind lidar (CDWL) during three years from 1997 to 1999.
- JAXA AO for Phase 2 utilization JEM-EF (November, 2006). NICT proposal has not been selected in 2006.
- NICT started feasibility study for the space-borne CDWL as one of future post-GPM missions in 2009 again.
- Japanese science working group was organized in 2011 and is studying feasibility of the space-borne CDWL from the technical and scientific viewpoints (2011-).

◆ Objectives of this study

Motivations of this study are to develop key 2-μm technology meeting technical requirements for a future space-based CDWL and to enhance feasibility of wind measurement from space.

Collaboration framework for space-borne Doppler lidar

JAXA

TU, UT, KU,
RIKEN, NIES

Satellite and space-qualified laser

- Orbit
- Electrical power
- Thermal control

Space-borne coherent Doppler Wind lidar

Study on data assimilation system for cloud and precipitation from satellites

- Establishment of OSSE (SOSE and full OSSE)
- Initial test conducted by space-borne Doppler lidar

TIT,
NIES

NICT

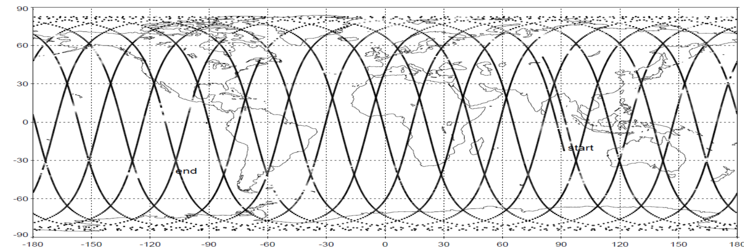
JMA/MRI

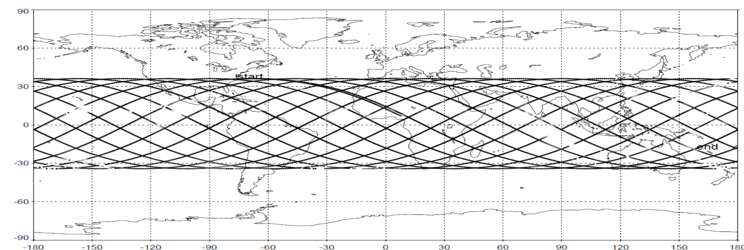
Lidar simulation and SOSE-OSSE

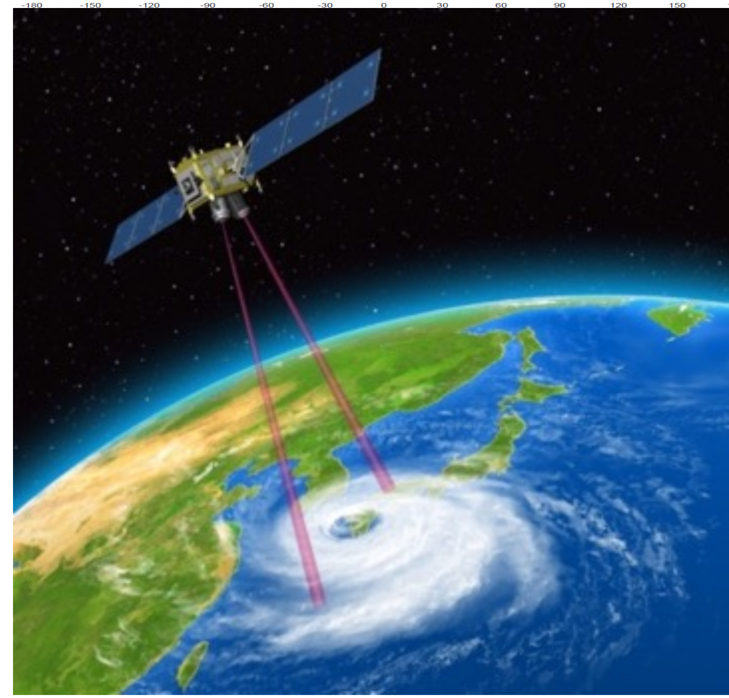
- Pseudo-truth atmospheric data and aerosol model (MRI to NICT)
- Simulated LOS wind speed and error (NICT to MRI)
- SOSE-OSSE (MRI)

Concept of super-low-altitude-satellite-borne DWL

	Super Low Altitude space-borne Coherent Doppler Wind Lidar
Orbital altitude Orbit	180-270 km Polar orbit / Low-inclination orbit
Transmitter	2-µm laser (125 mJ, 30 Hz)
Receiver	0.4 m (primary mirror) x 2 Heterodyne detection
Target horizontal resolution	<100 km
Target vertical resolution	Altitude 0-3 km: <0.5 km Altitude 3-8 km: <1 km Altitude 8-20 km: <2 km
Nadir angle	~35 degree
Looking angle	45 and 135 degrees
Target horizontal wind	-100~100 m/sec

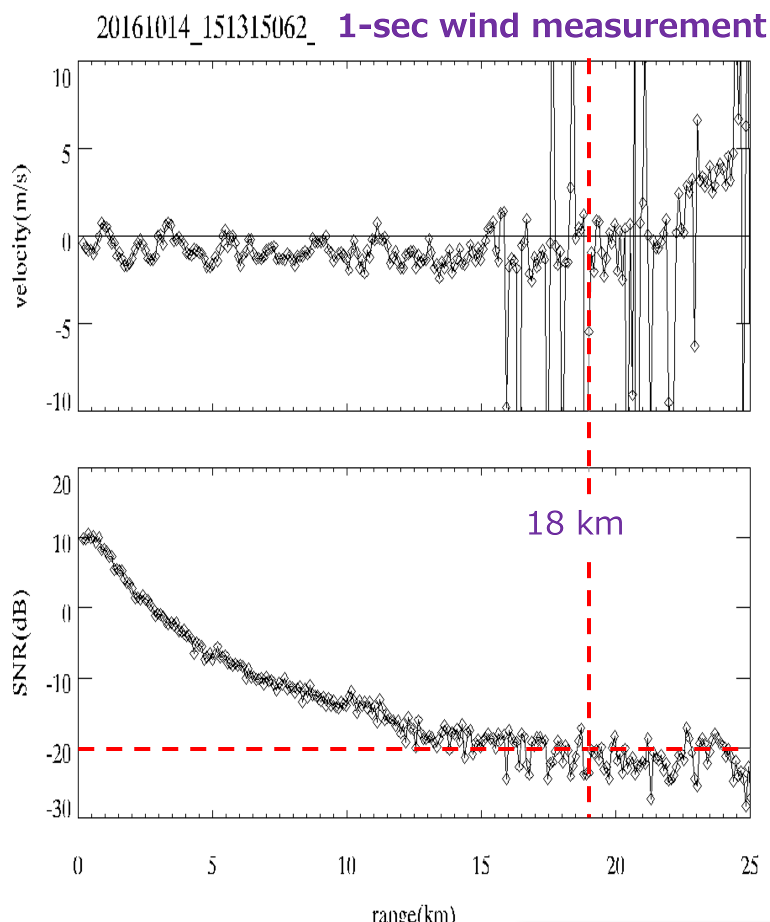


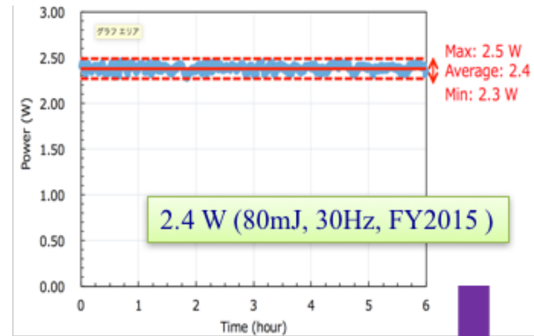


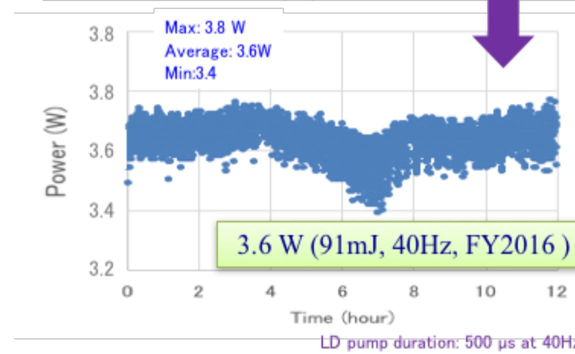


Schedule of Super Low Altitude Test Satellite
Milestone
2018: Launch
2018-2019: Experimental flight
2019-: Additional flight

Ground-based 2-μm Doppler Wind lidar







Shot noise = 9.2 dB

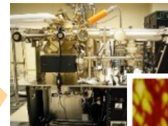
Hamamatsu C5658-4973

http://www2.nict.go.jp/res/lidar/QL/CDWL/index.html
http://www2.nict.go.jp/res/lidar/QL/DopplerLidar/

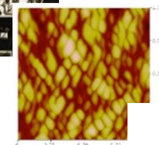
Optimization
- Pump duration, PRF
- Focal length of receiver
- Heterodyne detection

Development of single-frequency high pulse-energy 2-μm laser

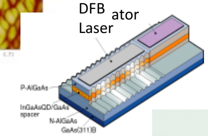
2μm Quantum-dot laser **NICT**



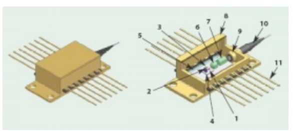
PDLに設置されている分子線エピタキシー装置



分子線エピタキシー装置を用いて作成された量子ダッシュ構造



量子ドットレーザ試作



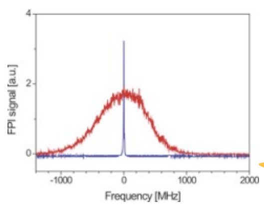
2μm Quantum-dot laser (pigtail, Future)

2μm semiconductor laser

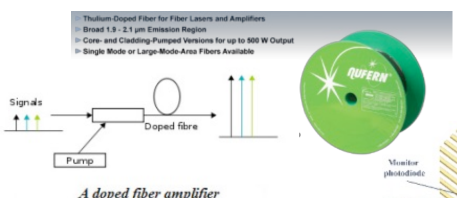
2μm optical fiber amplifier

2μm single-frequency high pulse energy laser

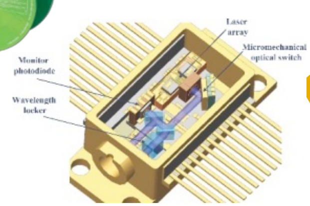
Narrow line width, high power, high stability



2μm optical fiber amplifier

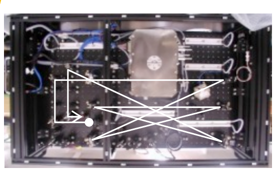


NICT



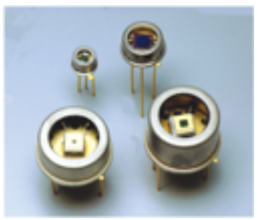
2μm Quantum-dot laser + AMP (pigtail, Future)

2μm pulse laser



NICT, TIT

2μm detector (Future)

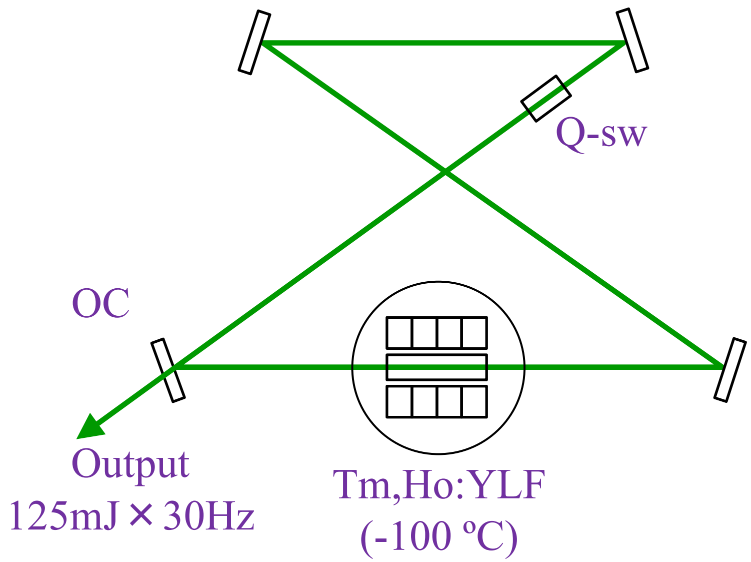


Commercial detector (non space -qualification)

NICT

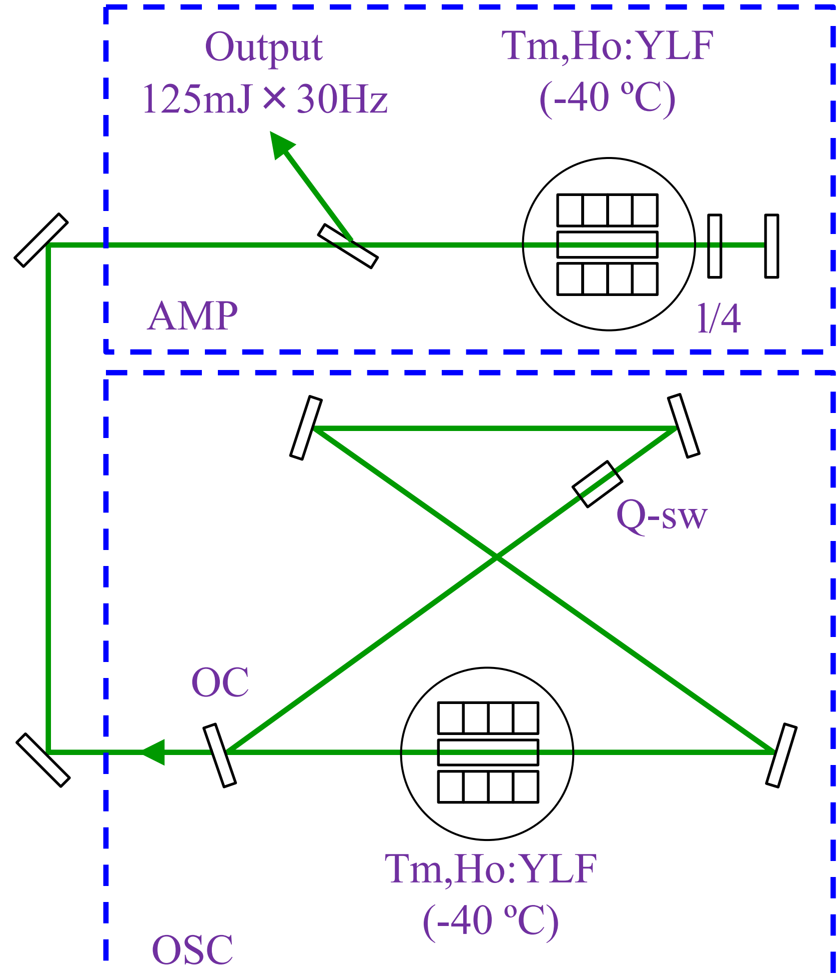
2μm laser block diagram

1 Oscillator



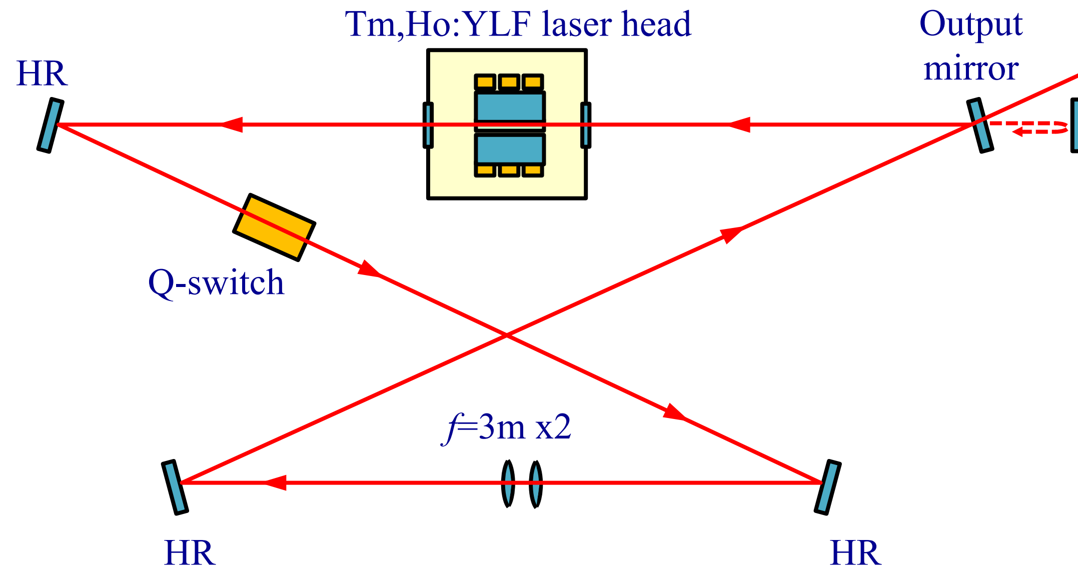
- Understanding of characteristics of Q-switched Tm,Ho:YLF laser at operating temperature at -80 ~ -40 ºC.
- Investigation of parameter required for the design of a laser transmitter operating temperature at -80~-40 ºC.

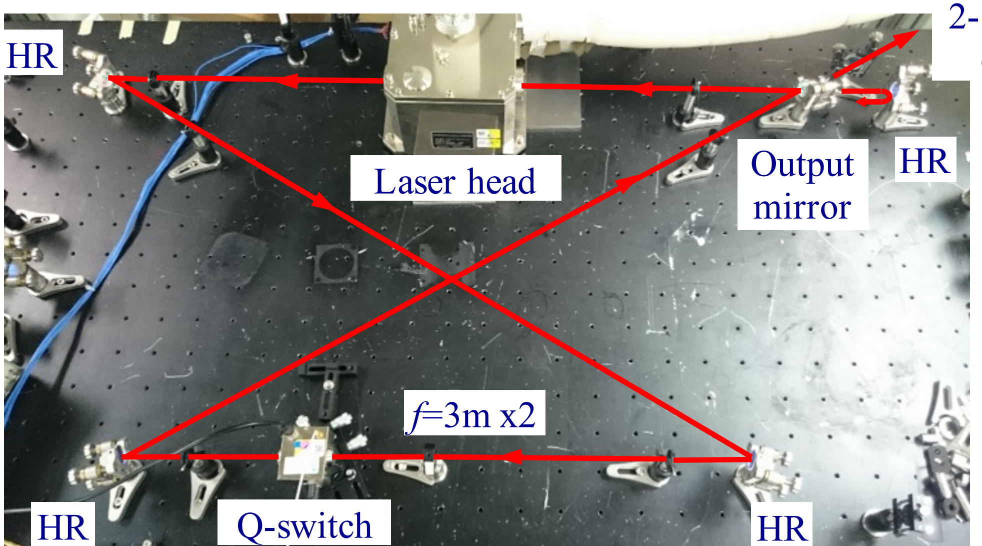
1 Oscillator+ 1 Power amplifier



OC: Output Coupler

Setup for laser experiment: one oscillator





2-μm laser output

<u>Laser rod</u>

- Rod : Tm,Ho:YLF
- Diameter / Length

1st generation : 8 mm / 50 mm
2nd generation : 4 mm / 44 mm
<u>3rd generation : 4 mm / 33 mm</u>

<u>Operating conditions</u>

- Pulse repetition frequency: 50, 70Hz
- Pump pulse length : 800, 600 μs
- Resonator length : 3.86 m

<u>HR mirror</u>

- High reflection at 2051 nm, flat

<u>Output mirror</u>

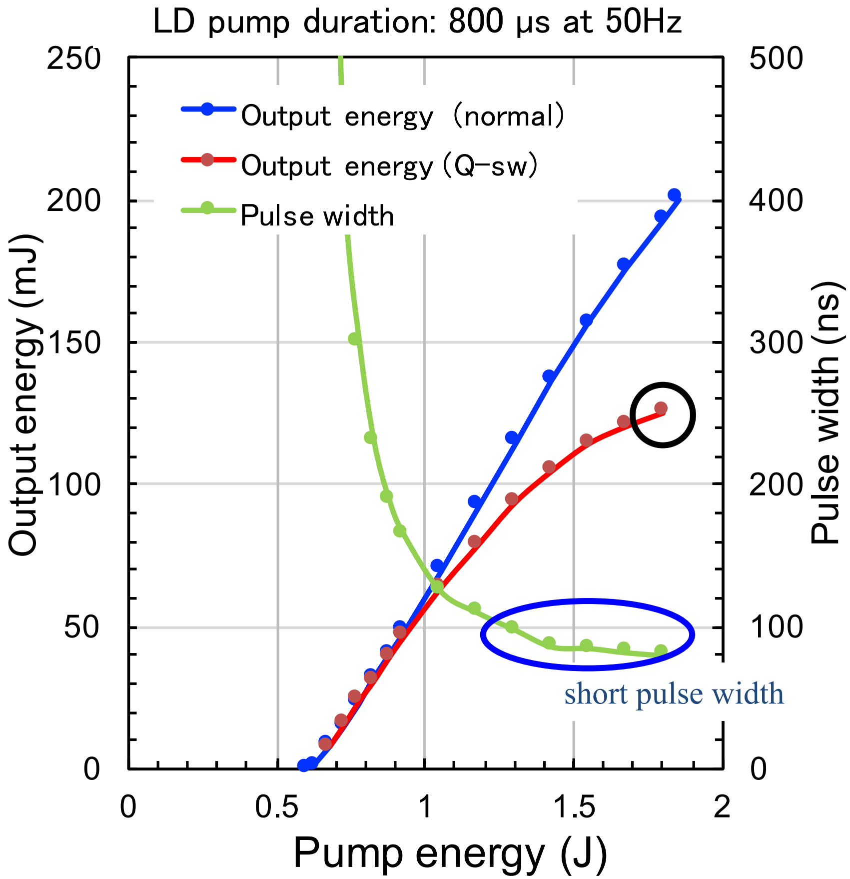
- *R*=61%, flat

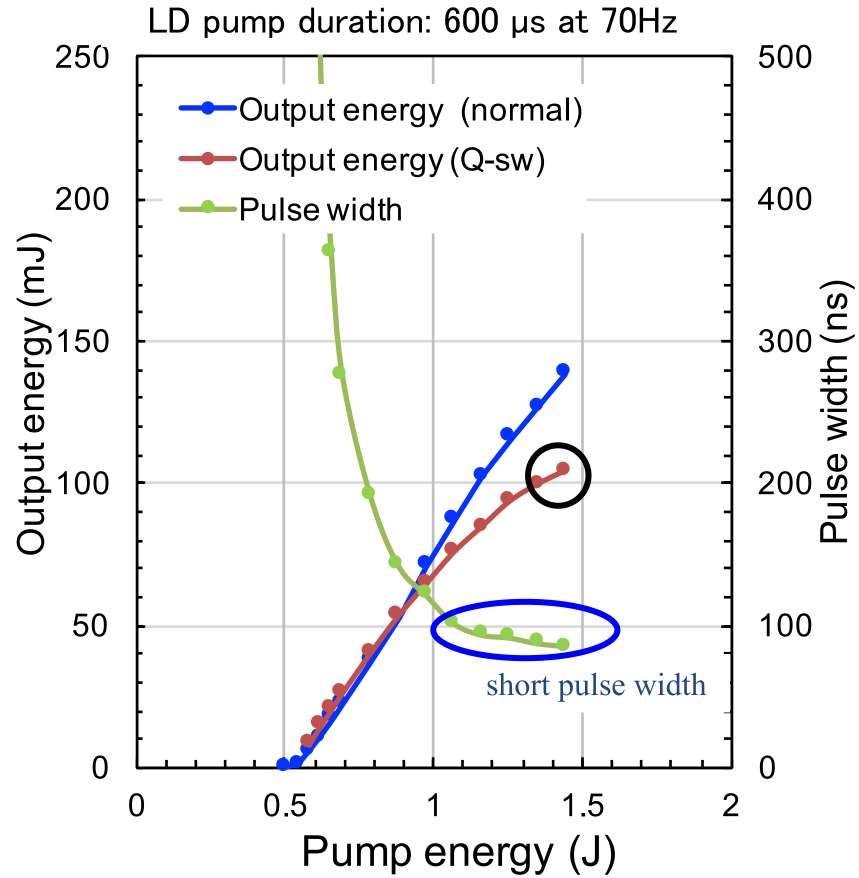
<u>Q-switch</u>

- Fused silica, RF signal: 27.12MHz

Output pulse energy using 3rd generation laser head

O.C. reflectivity: 61 %
Laser rod was cooled down to about -80C.

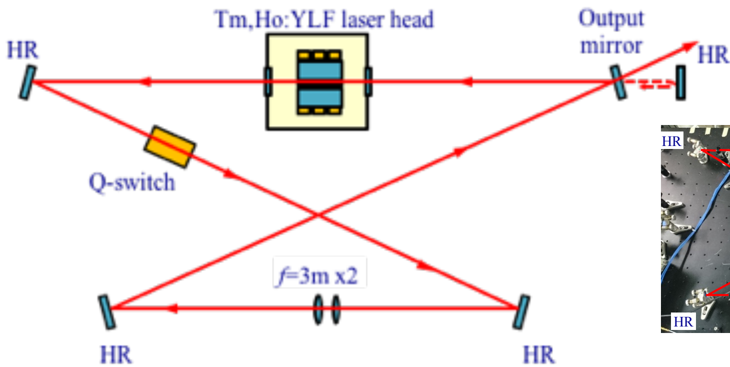


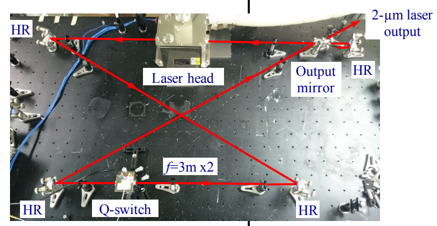


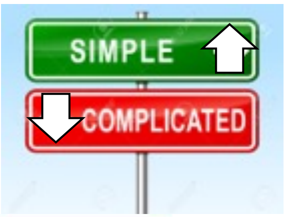
125 mJ at PRF of 50Hz (6.3 $W_{average}$)
(Target energy: 125 mJ at PRF of 30Hz.)
$M^2 < 1.5$
Energy･√PRF=0.88 (Target: 0.68)

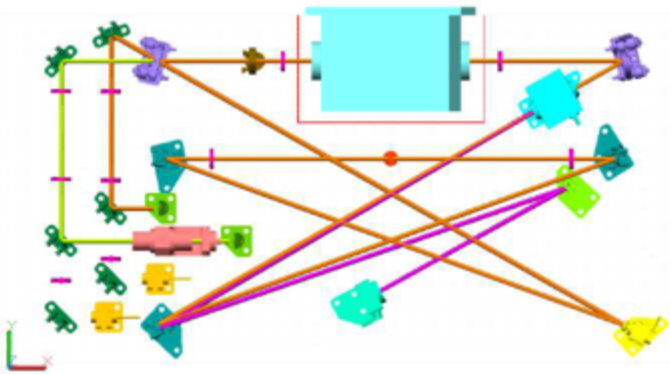
104 mJ at PRF of 70Hz (7.3 $W_{average}$)
(Target energy: 125 mJ at PRF of 30Hz.)
$M^2 < 1.5$
Energy･√PRF=0.87 (Target: 0.68)

Concept of simple MOPA-configuration laser

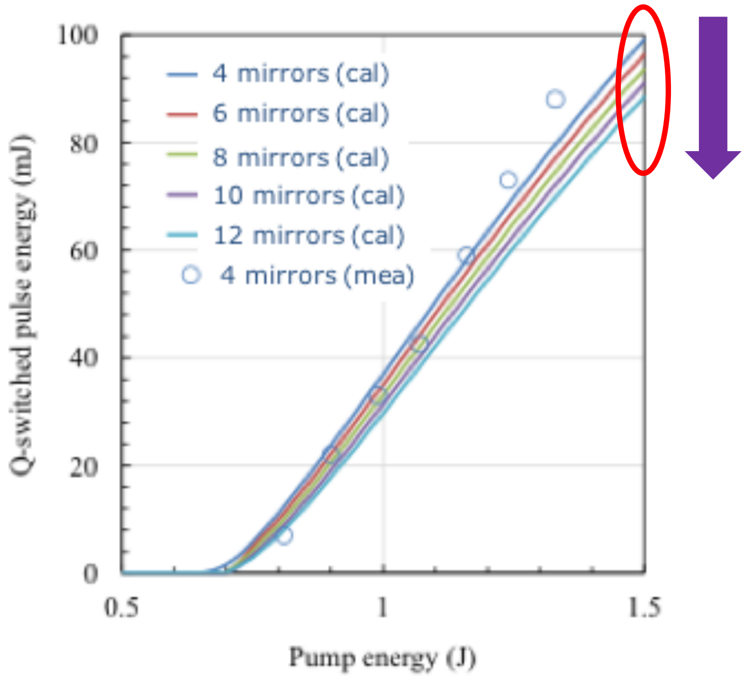








Design concept
- Simple ring laser design
- Compact ring laser design
- Easy optical alignment

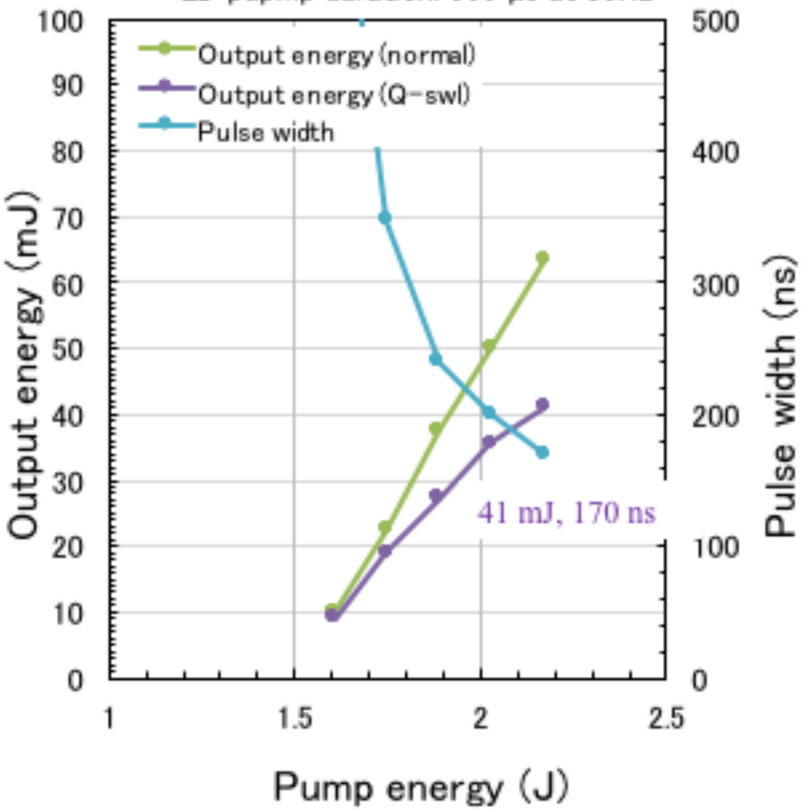


2[nd] generation

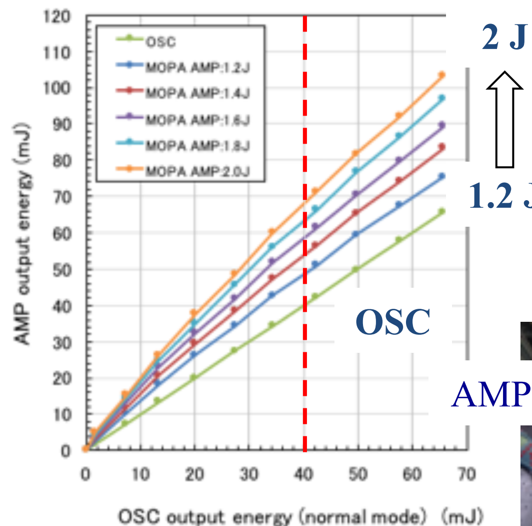
Preliminary result of MOPA-configuration laser

Output pulse energy
(Laser rod temperature: -40 C)

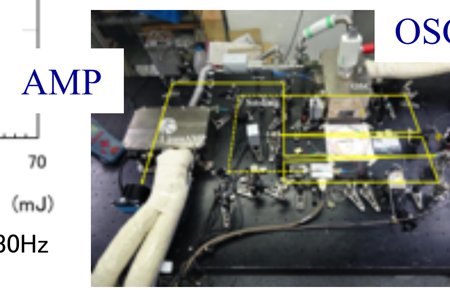
LD pupmp duration: 900 μs at 30Hz



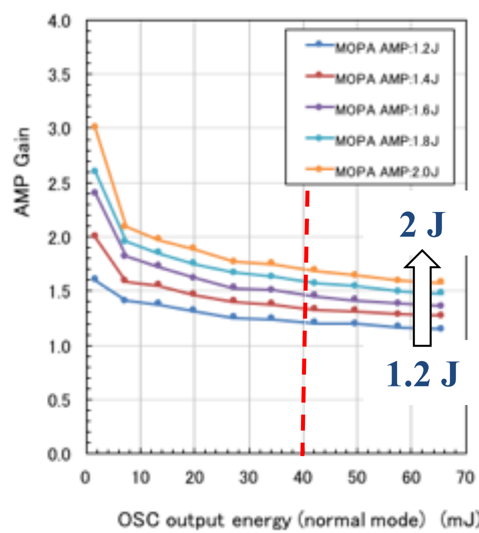
LD pump duration fro AMP: 1 ms at 30Hz



Output energy:
50 -70 mJ



LD pump duration fro AMP: 1 ms at 30Hz

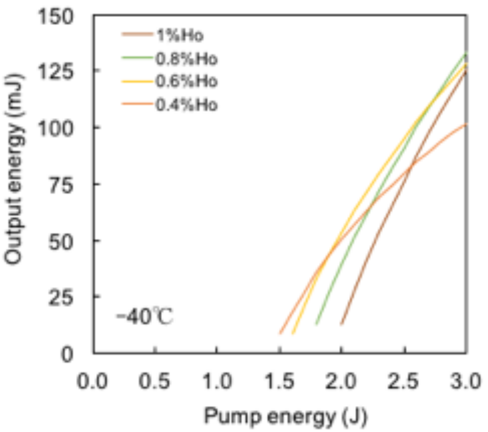


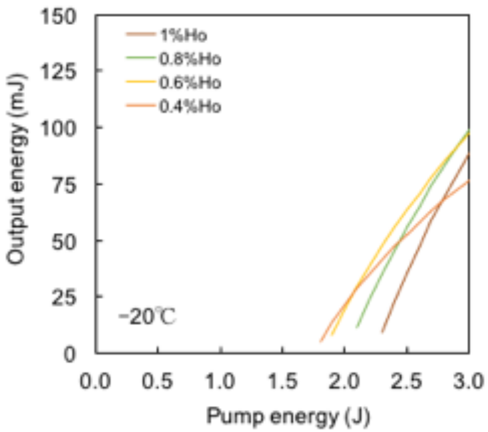
Preliminary result for 1-pass AMP

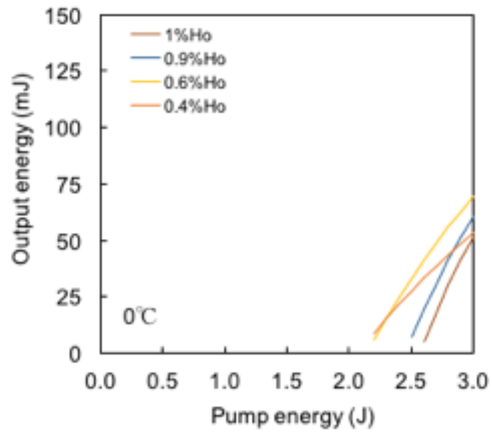
Gains were :
1.3 to 1.8.

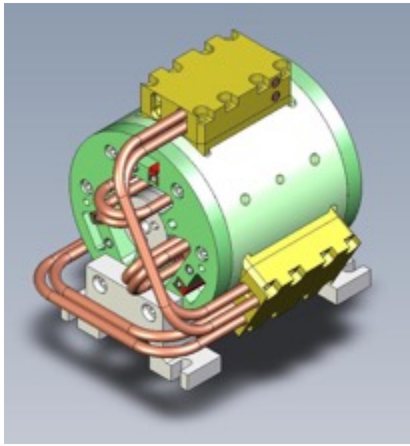
Operation temperature considerations: Tm,Ho:YLF laser

33-mm-long Tm,Ho:YLF laser rod

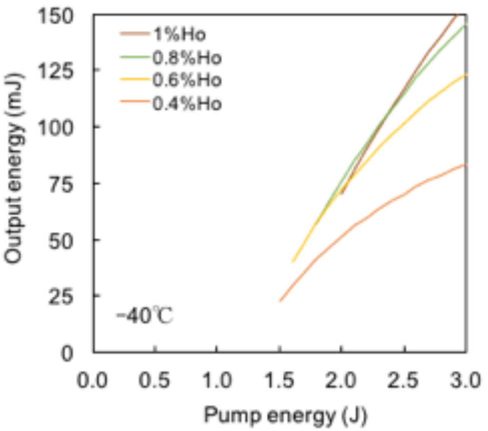


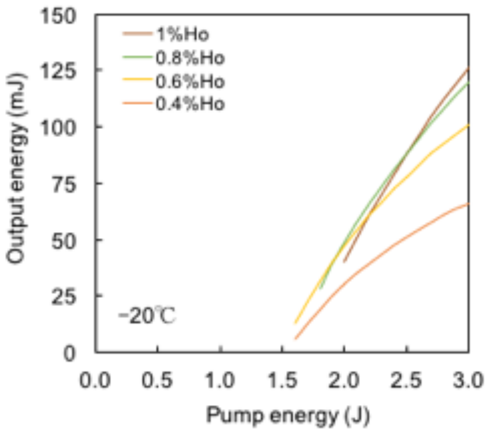


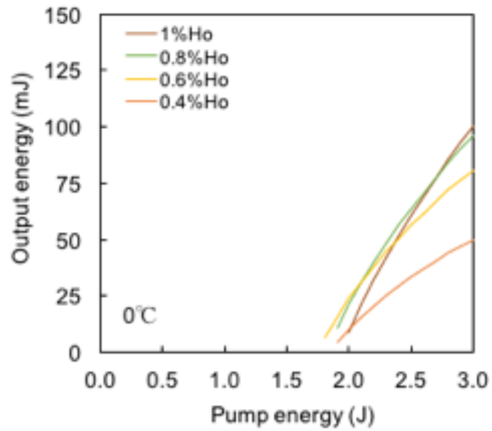




22-mm-long Tm,Ho:YLF laser rod

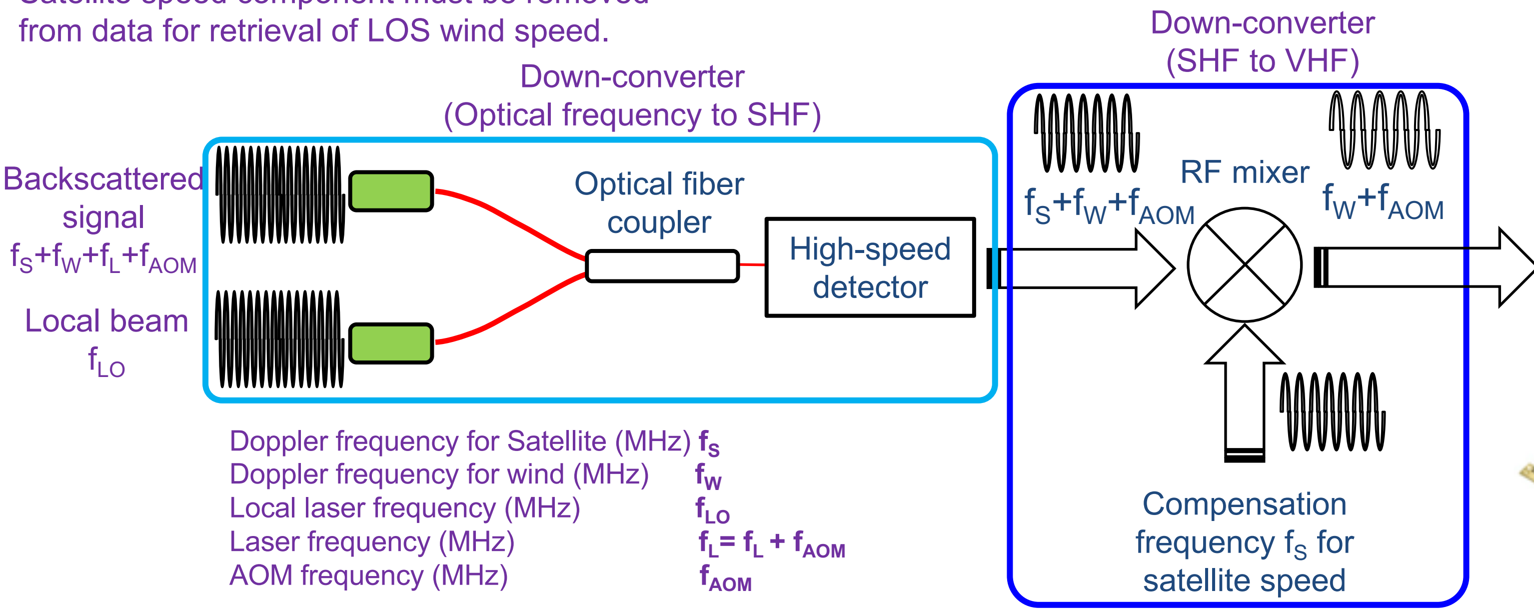




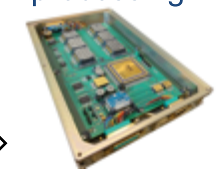


Signal flow considerations: down-convert from optical region to RF region

Satellite speed component must be removed from data for retrieval of LOS wind speed.



On-board processing



Data storage

	200 MHz/8 bit ADC	400 MHz/14 bit ADC
Satellite speed at an orbital altitude of 220km (m/sec)	7777	7777
Nadir angle (degree)	35	35
Looking angle (degree)	45 and 135	45 and 135
Horizontal wind speed range (m/sec)	-100 - 100	-150 - 150
LOS wind speed range (m/sec)	3114 – 3195	3093 – 3215
LOS wind frequency f_S at 2-μm (MHz)	3114 – 3195	3093 – 3215
Compensation frequency f_S at 2-μm(MHz)	3100	3050
AOM Frequency (MHz)	40	105
Down-converted LOS wind speed range (m/sec)	14-95	43-165

High-speed detector is required for space-based DWL measurement.

High-speed 2-µm InGaAs photo diode

1. Target cut-off frequency is more than **8 GHz**.
2. Output: AC coupled.
3. Measured using a single-mode fiber (FC/Angled PC).
4. Wavelength for inspection is 1.55um only.
   Photosensitivity at 2050 nm is guaranteed by design.

Target specifications (design)

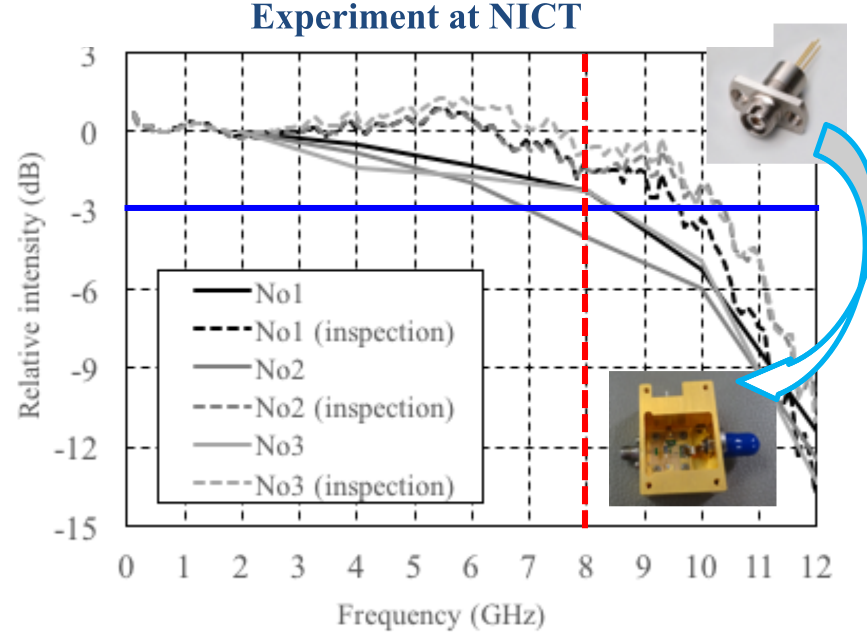
1.2 Electrical and Optical Characteristics
(Unless otherwise specified, Tc=25℃,Vcc=3.3V,Vpd=TBD,Vee=0V, RL=50Ω*1, λ=1.55um)

Parameter	Symbol	Condition	Min.	Typ.	Max.	Unit
Active Area	A	-	-	TBD	-	um^2
Spectral Response Range	λ	-	-	0.9 to 2.2	-	um
Peak Sensitivity Wavelength	λp		1.85	1.95	2.05	um
Photo Sensitivity*3*4	S1	λ=1.55um*4	-	0.85	-	A/W
	S2	λ=2.05um*4	-	1.15	-	A/W
Dark Current	I_D	Dark state	--	TBD	TBD	nA
Supply Current	Icc	Dark state, R_L=∞	--	50	75	mA
Output Bias Voltage	Vo	Dark state, R_L=∞	--	1.85	--	V
Output Offset Voltage	Voff	Dark state, R_L=∞	-	5	--	mV
Cut-off Frequency *1*2*3*4	Fc	Pin=-18dBm, -3dB	--	TBD*5	-	GHz
Low Cut-off Frequency*1*2*3*4	fc-L		--	40	--	kHz
Photo Sensitivity *1*2*3*4	S	Pin=-18dBm	--	12	-	V/mW
Max Power (Linearity) *1*2*3*4	Pmax	10% down	--	0	-	dBmOMA
Max Output Voltage *1*2*3*4	Vomax		--	400	-	mVpp
Noise Equivalent Power*1*2*3*4	NEP	to 9GHz	-	1.8	-	uWrms
Output Resistance*1*2	Ro	-	--	50	--	Ω

Trial product (inspection)

parameter	active Area	Photo Sensitivity (PD)	Dark Current	Supply Current	Output Bias Voltage	Output Bias Voltage	Output Offset Voltage	Cut-off Frequency	Photo Sensitivity (PD+TIA)	Max Power	Noise equivalent Power
	受光面ｻｲｽﾞ	受光感度 (PD部)	暗電流	電源電流	出力 ﾊﾞｲｱｽ 電圧	出力 ﾊﾞｲｱｽ 電圧	出力 ｵﾌｾｯﾄ 電圧	遮断 周波数	受光感度 (PD+TIA)	最大 光量	雑音等価 電力
symbol	A	S1	ID	Icc	Vo+	Vo-	Voff	fc	S	Pmax	NEP
S/No. / parameter	um	A/W	nA	mA	V	V	mV	GHz	V/mW	dBmOMA	uWrms
5K70050	φ24	1.1	4	50	2.841	2.837	4	9.6	0.23	>+2	2.0
5K70051		1.1	8	51	2.842	2.831	11	10.4	0.24	>+2	2.0
5K70052		1.1	9	51	2.861	2.849	12	9.9	0.25	>+2	1.9
判定		良	良	良	良	良	良	良	良	良	良

Experiment at NICT



Data rate considerations: Time domain

	200 MHz/8 bit ADC	400 MHz/14 bit ADC
Orbital altitude (km) Orbital period (sec)	220 5323	220 5323
Target data range (km) Duration (μs/shot)	0-22.5 150	0-22.5 150
Laser pulse repetition frequency (shot/s, Hz)	30	30
Data per shot (Mbps) • Reference data (outgoing pulse) • Atmospheric data	8.2 1 7.2	26.2 1 25.2
Housekeeping data (Mbps)	1	1
Total data rate (Mbps)	9.2 (=1+8.2)	27.2 (=1+26.2)
1 orbit data storage (Gbit/orbit)	49	149
24-hrs data storage (Gbit)	793	2412

Data rate considerations: Frequency domain

	1 sec, 200MHz ADC	200 MHz ADC (1-sec average)	400 MHz ADCADC (1-sec average)
Orbital altitude (km) Orbital period (sec)	220 5323		
Target data range (km) Duration (μs/shot)	0-22.5 150		
On-board FFT (Reference/ signal) • Sampling point • Frequency resolution (MHz/bin) • Frequency bin • Range resolution (m/range-gate) • Number of 1 range-gate • Data type (bit)	 1024 / 128 0.20 / 1.56 512 / 64 96 235 64 (8 byte)	 1024 / 128 0.20 / 1.56 512 / 64 96 235 64 (8 byte)	 2048 / 256 0.20 / 1.56 1024 / 128 96 235 64 (8 byte)
(Reference data) Frequency-spectrum data (Kbps)	33 = 64 bit/bin x 512 bin	33 = 64 bit/bin x 512 bin	66 = 64 bit/bin x 1024 bin
(Reference data) Additional 64-bit data (Kbps)	0.640 = 64 bit x 10/profile	0.640 = 64 bit x 10/profile	0.640 = 64 bit x 10/profile
(Atmospheric data) Frequency-spectrum data (Kbps)	965 = 64 bit/bin x 64 bin/range x 235 range	965 = 64 bit/bin x 64 bin/range x 235 range	1929 = 64 bit/bin x 128 bin/range x 235 range
(Atmospheric data) Additional 64-bit data (Kbps)	301 = 64 bit x 20/range x 235 range	301 = 64 bit x 20/range x 235 range	301 = 64 bit x 20/range x 235 range
Total data rate (Mbps)	39 = 30 x (33+0.64+965 +301)	1.3 = 33+0.64+965 +301	2.3 = 66+0.64+1929 +301
Housekeeping data + others (Mbps)	1	1	1
Total data rate (Mbps)	40	2.3	3.3
1 orbit data storage (Gbit/orbit)	213	13	18
24-hrs data storage (Gbit/day)	3454	199	285

Summary

Recent research and development for 2-micron coherent Doppler Wind Lidar at NICT were reported in the presentation:

- Q-switched output pulse energy at 50 and 70 Hz were 125 and 104 mJ. Development of one oscillator meeting the requirements for the space-based CDWL is technically feasible.
- NICT develops a new 2-μm ring laser at a laser rod temperature of -40C. Preliminary result of the new 2-μm ring laser experiments was 41mJ for OSC and 105 mJ for AMP at 30Hz.
- Numerical laser simulations for laser rod temperature of -40C, and -20C and 0C show that output pulse energy decreases with the laser rod temperature rise.
- Signal flow was investigated in optical and RF regions. The flow indicates the required BW of a detector is faster than 3.3 GHz. We developed a new 2-μm detector with BW of >8GHz.
- Data rate considerations were investigated in time and frequency domains. The result shows that we can reduce data rate using frequency-domain data.

<u>Future works:</u>

- Improvement of 2-μm laser head module.
- Development of single-frequency semiconductor laser
- Demonstration of a single-frequency semiconductor laser with optical fiber amplifier
- Demonstration of a new 2-μm ring laser meeting the requirements for the space-based CDWL
- Environment test